THE DEPARTMENT OF ENERGY'S

Bridge to the Corn Ethanol Industry

U.S. DEPARTMENT OF ENERGY
OFFICE OF ENERGY EFFICIENCY AND RENEWABLE ENERGY
OFFICE OF TRANSPORTATION TECHNOLOGIES

Prologue

The United States is a nation of vehicles, a land where the culture of the automobile is more strongly entrenched than anywhere else on the planet. From Ford's Model T, through the fins of the 1950s and 1960s, to the immense popularity of the sport utility vehicle of today, Americans have identified themselves with, and by, their choice of cars. This fascination with the automobile, however, has considerable downsides: emission of greenhouse gases and other pollutants that impact the health of the planet and its people, and consumption of huge volumes of imported fuels that contribute to the national trade deficit.

Despite the introduction of commercial electric vehicles, improvements in conventional engine efficiency, and advances in other automotive technologies, automobile use continues to negatively affect our environment and economy. Approximately one-third of US carbon dioxide (CO_2) emissions are generated by producing and consuming transportation fuels. Vehicle emissions account for 60 percent of urban air pollution, and contain untold millions of pounds of EPA criteria pollutants including sulfur dioxide (SO_2), oxides of nitrogen (NO_x), and particulate matter. The nation's 185 million vehicles consume nearly 70 percent of all the crude oil used in the US—roughly half of this oil is imported, creating a $66 billion oil trade deficit. Some experts predict the US will import 74 percent of its oil by 2020, generating a $170 billion oil trade deficit. Much of this oil is imported from politically unstable regions, potentially compromising the energy security and economic stability of the Nation.

Individuals within government, academia, and the private sector have, in the past, issued calls for domestically-produced, cleaner-burning, economically-viable transportation fuels. Ethanol is an answer to this call.

Ethanol: A home-grown alternative fuel solution to the Nation's needs

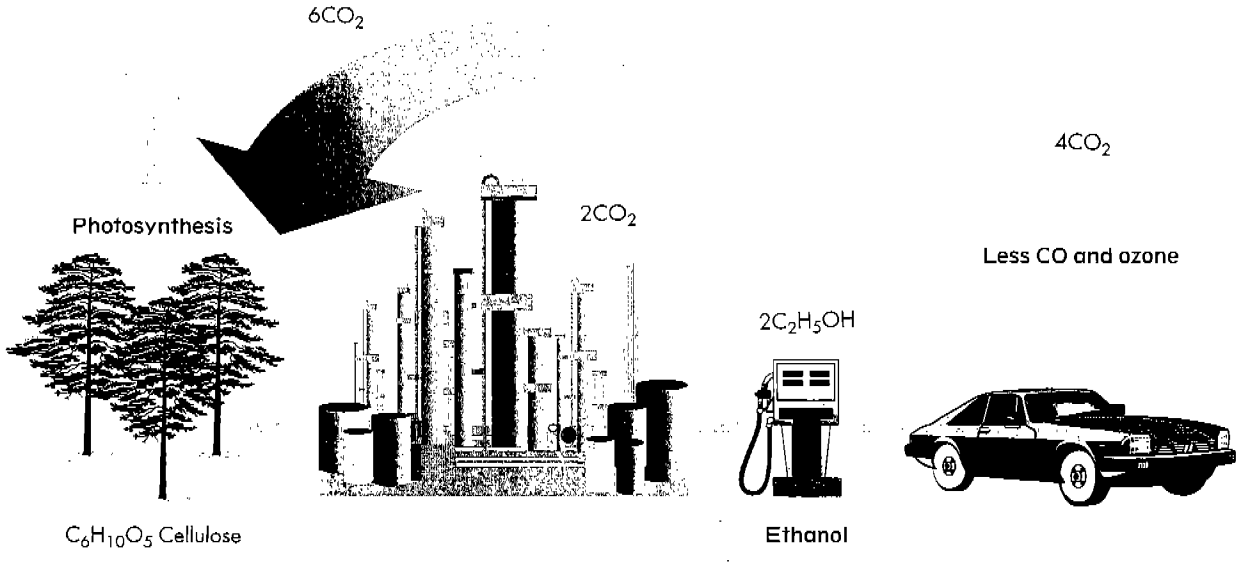
Ethanol is a clean-burning, non-petroleum liquid fuel. 90 percent of the ethanol produced domestically is derived from an abundant, renewable feedstock—the starches found in corn kernels. Using a fairly simple process that involves conversion of corn starches to sugars, fermenting the sugars to produce ethanol, and then distilling the ethanol into its final form, production plants today generate approximately 1.5 billion gallons of ethanol annually.

Closing the Carbon Loop and Reducing Emissions

Producing and using ethanol as a transportation fuel can help close the carbon loop and reduce atmospheric CO_2 buildup in two important ways: by displacing the use of fossil fuels, and by recycling the CO_2 that is released when ethanol is combusted. Combustion of ethanol is CO_2 neutral, in that the CO_2 emitted to the atmosphere during its combustion is offset by the CO_2 removed from the atmosphere by the corn from which it is derived. In addition to closing the carbon loop, using ethanol instead of fossil fuels avoids the emission of CO_2 locked in the earth as petroleum for millions of years. This aids in slowing the global carbon imbalance and helps reduce atmospheric CO_2 levels that contribute to global warming.

The Ethanol Production Loop

CO_2 released during conversion and use is captured by plant growth



Ethanol's other Benefits

The clean burning nature of ethanol and its domestic production are its two obvious benefits; less well publicized, however, are its many other advantages. Wet mill ethanol plants co-produce distillers dried grains, an important feed product for livestock. A healthy ethanol industry provides corn growers with a non-food market for their product, thus helping to maintain the price levels of corn, and insulating growers from some market shocks. Ethanol plants offer employment in rural areas, and the substitution of ethanol products for petroleum products reduces the national trade deficit and the Nation's dependence on foreign oil.

Economic Challenges facing Ethanol

Ethanol producers are, at present, almost wholly reliant on supplies of corn as their feedstock. The anticipated and projected demands for ethanol, however, indicate that rapid ethanol production growth will increase the industry's demand. Some of this demand will be met by reallocating corn from the food market, although upward pressure on the price of corn is likely inevitable. This price will continue to rise in step with demand for ethanol, eventually resulting in ethanol costs that are too high for the market to bear, thus reducing demand, and lowering the price of corn to market equilibrium prices.

Ethanol producers are also subject to, and constrained by, external market forces. If international demand for corn rises considerably, the world price for corn will rise to a point where ethanol production is economically untenable.

Corn ethanol is, largely, a supplementary product to gasoline and hydrocarbon-based oxygenates such as MTBE, and thus the price for ethanol cannot rise much above that for gasoline or competing oxygenates. As the prices for gasoline and non-ethanol oxygenates fluctuate in a free market, so too will the price of ethanol. And as the production volumes of ethanol are relatively small, producers can do little to influence these price shifts.

This situation places an unfortunate supply-side ceiling on the demand for corn ethanol—at present, ethanol producers would be unable to produce sufficient volume to meet a significant increase in demand—and a demand-side damper on the price of ethanol, limiting its ability to carve market share. While there is little that can be done to remedy this demand-side malady, there are options to circumvent the present supply-side ceiling; namely, the introduction of new feedstocks for the production of ethanol.

The New Feedstocks

Past research and development efforts undertaken by the private sector, universities, and the Departments of Agriculture and Energy have shown the technical viability of using a variety of feedstocks to produce ethanol.

The Chemistry behind Conversion

Like the starch found in corn, cellulose and hemicellulose are carbohydrates composed of chains of sugars bonded together. But the sugars in cellulose and hemicellulose are joined differently than in starches; the cellulose chains are also interconnected in a crystalline structure. These differences provide the rigidity and the indigestibility that we associate with wood and straw. The common enzymes used to convert starch to sugar in human digestion or beverage brewing do not work on cellulosic materials.

Researchers at the National Renewable Energy Laboratory (NREL) and elsewhere, however, have developed a sophisticated set of biotechnological and thermochemical tools to break the interconnecting bonds in cellulose and hemicellulose and make it possible to produce ethanol from these carbohydrates. Cellulase enzymes can be used to convert cellulose to sugars that can then be fermented to ethanol by yeast. These enzymes are naturally produced by fungi.

Although hemicellulose is easier to break down into sugars than cellulose, the primary sugar obtained, xylose, is not fermentable by common yeasts. Researchers developed a way to overcome this problem by using genetically-engineered yeasts and genetically engineering bacteria that can directly ferment the xylose. Much work is presently underway to select appropriate yeasts and bacteria.

Recent research and development activities focusing on the use of corn stover, bagasse, and rice straw show extraordinary promise as complementary feedstocks for the production of ethanol.

Corn stover, a generic term for leaves, stalks, and sometimes cobs, represents the largest available feedstock in the United States. Its cellulosic structure presents a rich source of potential energy for conversion to ethanol.

Technology is the key to the economic use of corn stover. Recent advances in research supported by the Department of Energy (DOE) are moving the use of stover closer to industrial reality. And corn stover is just the beginning. Other feedstocks, ranging from rice straw to sugar cane bagasse, offer alternative energy opportunities as well.

Two points argue convincingly for corn stover as the logical starting place for further development—volume and experience. U.S. farmers plant approximately 80 million acres of corn each year, with a potential stover harvest of some 120 million dry tons. More than 90 percent of the ethanol now produced in the United States comes from corn kernels. Thus, processors are already familiar with production techniques, methods, and equipment, and may need only expand to accommodate stover rather than build new plants. These two facts alone significantly reduce the financial uncertainties early biomass ethanol producers must face.

Corn stover, a promising bio-ethanol feedstock, possesses many positive operational and supply characteristics. Harvesting only 30% of the available crop, roughly 80 million dry tons, would allow the production of 6 billion gallons of ethanol.

The Bridge to the Corn Ethanol Industry

The Bridge to the Corn Ethanol Industry activity, established by the Department of Energy and it's national laboratories, is designed to foster greater cooperation, understanding, and working relationships between policy setters in government, university researchers, national laboratories, and companies involved in the production of ethanol. Through such operators as financial support, greater dissemination of research findings, development of improved technology, and cooperative research and development agreements (CRADAs), DOE aims to expand the production potential of ethanol to meet forecasted demands, and carve a larger share of the domestic transportation fuels market for ethanol.

The Bridge to the Corn Ethanol Industry activity is industry-guided. Its strength relies on the contributions of its participants. The Department of Energy's national laboratories, long leaders in the field of alternative fuels research, will form one half of the bridge. By soliciting private sector involvement, industry will form the other half of the bridge. Acting as the keystone to the *Bridge* activity is DOE's Office of Fuels Development, providing funding and support, facilitating cooperation and partnerships, and providing policy oversight to ensure the success of the activity. In this fashion, a "win-win" atmosphere will be created, allowing participants to gain from the others' experiences and know-how.

The Bridge to the Corn Ethanol Industry activity will benefit many involved in the agricultural and alternative fuels industries, from farmers to ethanol producers, by expanding the market diversity for spent grains and corn fiber, providing a greater range of feedstocks, and helping to stabilize and expand employment opportunities in rural America.

The strength of any bridge, however, is a function of its component parts. NREL will bring to the activity its position as the foremost alternative fuels research and development organization in the public sector. Industry will provide invaluable experiences with real-world application of technologies, intimate knowledge of the economics of ethanol production, and hands-on history with plant start-up and operation. The Office of Fuels Development will provide broad vision, helping guide the activity to ensure compatibility with Federal policy.

Past successes with CRADAs have established a framework for success, demonstrating the ability of industry, government, and national laboratories to work cooperatively to the benefit of a given project. Similar, if not better, results are expected from the *Bridge* activity.

Corn stover (or fiber)-to-ethanol conversion is, in many ways, an ideal addition to corn processing facilities because:

- Some of the infrastructure of the corn processing plant can be used, minimizing capital and operating costs and reducing the risk of implementing new technology.
- Corn fiber (as part of the kernel) is purchased for the primary milling operation, and is therefore readily available for conversion.
- Wet millers could make more effective economic use of their chief co-product (gluten feed) by using part of it (corn fiber) as an ethanol feedstock rather than selling it as a low-price co-product.

CRADAs - Predecessors to the *Bridge*

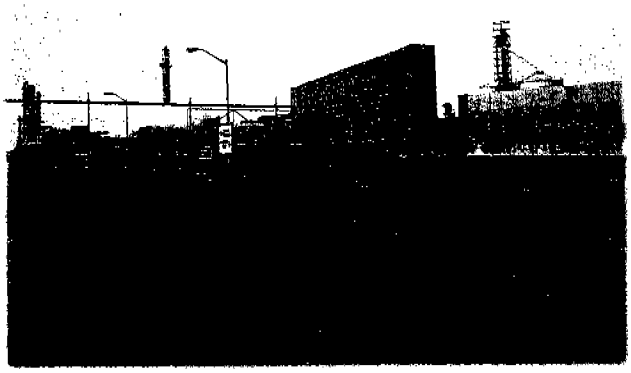
- NREL and the New Energy Company of Indiana teamed to design and demonstrate a process to obtain up to a 13% increase in ethanol yield from a given quantity of feedstock. The project focused on reprocessing 'leftover' materials from New Energy's dry-milling process to obtain additional carbohydrate-containing materials, and then feeding these carbohydrates back into the dry-milling process.
- NREL and SWAN Biomass Company (a partnership between Amoco Ethanol Development Corporation and Stone and Webster Engineering Industrial Technology Corporation) teamed to develop information at the pilot scale that could justify constructing a demonstration facility for converting biomass to ethanol.
- NREL and Delta-T formed a partnership to develop a process design and a rigorous capital and operating cost estimate for a commercial-scale biomass-to-ethanol facility.

The Bridge Today

DOE has already begun construction of the *Bridge* activity. In 1997, NREL completed its Cellulase Assessment, examining the availability of cellulase enzymes for commercial use. This assessment lays out a technical pathway to lower the cost of cellulase enzymes and make them readily available to ethanol producers. The challenges along this pathway must be met before practical production of ethanol from cellulosic materials can be attained.

During construction of the Assessment, NREL engaged numerous representatives from enzyme, grain processing/ethanol production, and engineering companies in both colloquia and one-on-one interviews. These individuals provided information to complete the Assessment. Following completion of the project, they were briefed on findings from the Assessment as well as present and future NREL research plans, and were offered the opportunity to candidly critique both. In addition, NREL and DOE continue to actively present their plans for the *Bridge* and research results at industry gatherings.

DOE and NREL will continue their efforts to gain a greater understanding of the ethanol industry by following up on the recommendations and findings generated from the Cellulase Assessment. This will include collaboration with industry to develop improved cellulase enzymes, and may also include further commercialization analyses, identifying new industrial partnering opportunities, and continuing research into more cost-effective production processes. To date, several of the topic areas have been incorporated in the *Bridge* Request for Proposals (RFP) discussed below, highlighting the desire of DOE to gain industry participation in overcoming the technical and economic challenges facing alternative feedstock ethanol production.



The New Energy Company of Indiana is a pioneer of the Bridge. The company's CRADA with the National Renewable Energy Laboratory explored the technical and operational merits of reprocessing 'leftover' materials, thus increasing ethanol yield from a given quantity of feedstock.

A recent private-sector project in Iowa demonstrated the practical and economic feasibility of harvesting and delivering corn stover for industrial use. Technological and procedural advances will allow delivery of stover at a cost of around $25 per dry ton, or $.30 per gallon of ethanol.

Another principle component of the *Bridge* today is hands-on, practical research. DOE and its national laboratories offer not only their technical and scientific expertise, but also their facilities. NREL's Alternative Fuels User Facility (AFUF) houses a dozen state-of-the-art laboratories dedicated to evaluating the commercial potential of bioethanol technologies. The Process Development Unit (PDU), the heart of the AFUF, is available to industry to test new enzymes, processes, or feedstocks. The PDU has been used successfully in past partnerships with AMOCO and SWAN. BC International, a company developing a bagasse-to-ethanol conversion process, is presently conducting work at the PDU.

Building the *Bridge* is also assisted by work conducted solely in and by the private sector. Beginning in 1996, Iron Horse Custom Farming, Western Iowa Development Association, and the Nishnabotna Valley Rural Electric Cooperative, working with an industrial processor, established a corn stover collection program. This full-scale project cost-effectively collected 50,000 tons of stover from 30,000 acres, at costs ranging from $31.60 to $38.15 per dry ton. Further improvements in cost structure and baling techniques should result in a cost of about $25 per dry ton, or roughly $0.30 per gallon of ethanol. DOE and its industrial partners are carefully watching the progress of this private-sector initiative for lessons to transfer to the *Bridge* effort.

Summary of the Cellulase Assessment

Results

- A general perception exists within the industry that the biomass hydrolysis commercialization concept is stale.
- The infrastructure required to support the use of alternative feedstocks is incomplete, though the degree of completeness varies by region and feedstock.
- Analytical results are difficult to compare.
- Assumptions are generalized.

Recommendations

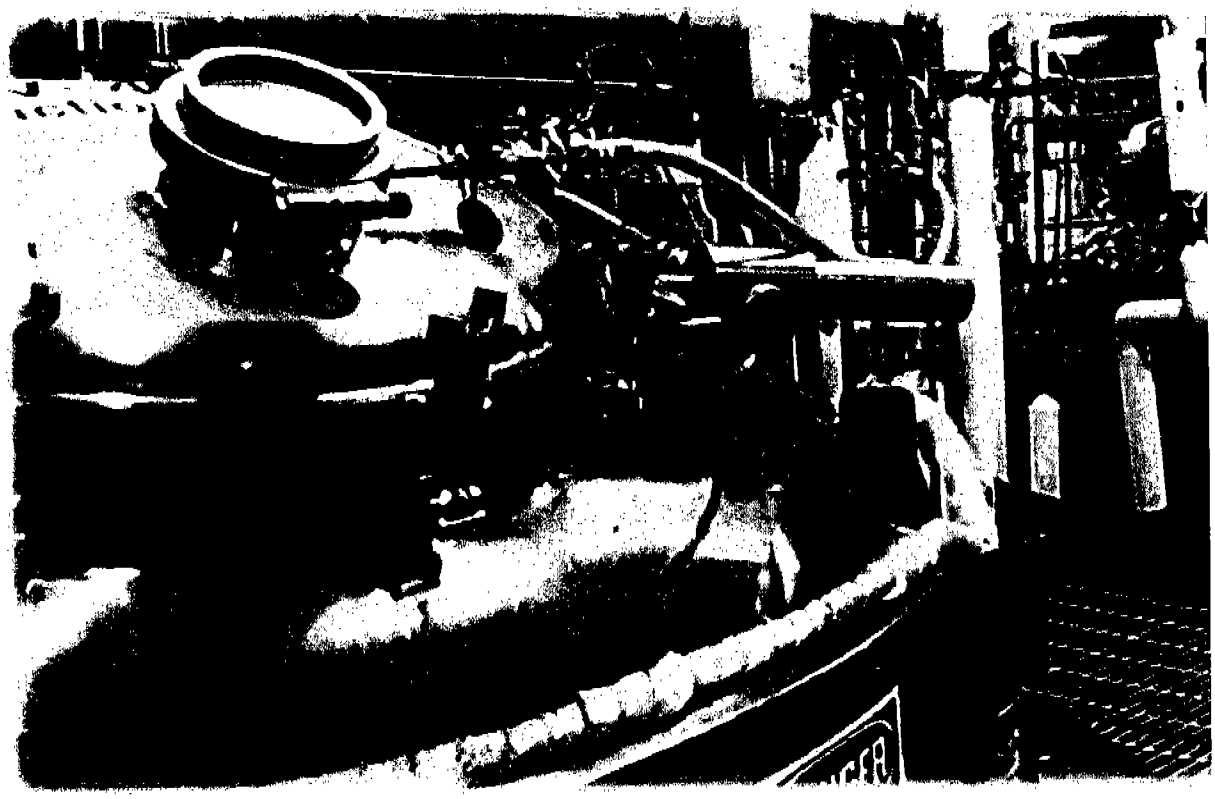
- Develop table of attractive cellulase enzyme market segments.
- Generate reverse income statements for these segments.
- Develop ethanol production cost model.
- Identify leading enzyme manufacturers and potential ethanol producers.
- Maintain and develop NREL's enzyme capabilities.
- Improve enzymes' production of desired outputs, in this case sugars.
- Continue investigation of the co-production of cellulase in plants.

The Bridge Tomorrow

To facilitate and encourage private sector participation NREL, at the request of DOE's Office of Fuels Development, has issued a Request for Proposals (RFP) entitled "Building a Bridge to the Corn Ethanol Industry." This activity will provide funding for studies to evaluate the cost of expanding existing grain processing facilities for cellulosic ethanol production. The studies will help identify economic opportunities for grain processors and enzyme manufacturers, and alternatives to improve feedstock collection and transportation. This RFP contains three primary project goals:

- Provide the grain processing industry the opportunity to explore the business potential provided by converting biomass to sugars via hydrolysis and fermentation to products such as ethanol;
- Take advantage of the grain processing infrastructure by investigating the local economic feasibility of biomass conversion facilities at an existing site; and
- Obtain feedback from the grain processing industry to guide research and development activities on biomass conversion research.

Issuance of this RFP is the Office's most ambitious *Bridge*-related effort to date, and concretely signals DOE's seriousness of purpose in this



NREL's Process Development Unit, the heart of the Alternative Fuels User Facility, is an integral component of Bridge-related research. The Unit is available to commercial partners working with NREL in a variety of feedstock and prcoess-development projects.

endeavor. This RFP lays out a series of aggressive project objectives, including:

- Identifying types, amounts, infrastructure requirements, and costs for potential biomass feedstocks;
- Identifying typical capital equipment located at a corn processing site and determining its availability for use by a co-located bioethanol facility;
- Identifying other infrastructure requirements;
- Identifying community and environmental issues that surround the construction and operation of a co-located bioethanol facility;
- Determining the production capacity;
- Determining equipment needs; and
- Producing financial performance projections and performing sensitivity analyses on the effects of cellulase enzyme and feedstock costs on the production of bioethanol.

It is anticipated that this RFP will spark widespread industry participation in cooperative ventures. This RFP is the first large-scale, public step taken by the Office of Fuels Development to fulfill its role as a facilitator and funder of opportunities for alternative feedstock development under the *Bridge* initiative.

The Future

DOE's Office of Fuels Development (OFD) has established ethanol production cost goals that propel research and technology development activities. By the year 2000, the goal is to demonstrate technologies and processes, in collaboration with industry, that are capable of producing ethanol from low-cost cellulosic feedstocks at a cost of less than $1.20 per gallon.

Partnerships established throughout the country are poised to build demonstration facilities. These commercial demonstrations are highly leveraged, industry-driven partnerships. Each of these facilities is being financed with an 80 percent or higher private sector investment and a 20 percent or less DOE cost-share. These partnerships are instrumental in achieving OFD's programmatic goals.

This year–2000 target is based on identification, evaluation, and conversion of feedstocks appropriate for developing near-term niche market opportunities. Niche market feedstocks are associated with an existing industry and are low- or negative-cost byproducts from the processing of crops into a primary product. For example, sugar cane is crushed to extract juice to make table sugar. The crushed cane, called bagasse, is an existing feedstock for biomass ethanol. These feedstocks provide an opportunity to establish biomass-to-ethanol facilities because of their low cost and potential for use with existing facilities.

Bridge-related partnerships and focused research and development

Feedstock research has identified numerous low- or no-cost by products that hold promise as alternatives to corn. Bagasse, a waste product of sugar cane processing facilities like the one shown here, may be an important regional feedstock in the future.

activities set out aggressive goals for the future of the ethanol industry. One of these goals is to demonstrate the commercial viability of producing ethanol from a variety of alternative feedstocks. This will require intensive cooperation among *Bridge* participants.

The role of agricultural cooperatives will be significant in the development of cellulosic ethanol production capacity. These cooperatives have at their disposal not only conventional ethanol feedstocks, but also massive quantities of stover that could be used in a properly designed ethanol facility. By taking advantage of cooperatives' established crop production and transportation infrastructures, cellulosic ethanol plants can vertically integrate, maintaining control over the product cycle from feedstock production to ethanol production. This will reduce supply fluctuations and leverage their existing infrastructure.

It is important to note that alternative feedstock conversion technologies are not designed to compete with the conventional corn processing infrastructure. *The Bridge to the Corn Ethanol Industry* activities are designed to allow market growth and are developed to realize the full potential of existing and future ethanol production technologies, processes, and infrastructures. DOE's programs are designed to make the ethanol market "pie" larger.

Closing Thoughts

Much of the public is becoming increasingly concerned over the real-world ramifications of global warming, while others wonder aloud about the wisdom of our nation's dependence on imported oil. These two factors are driving a public-private sector partnership to increase the production volume of a clean-burning, domestically-produced alternative to gasoline: ethanol. *The Bridge to the Corn Ethanol Industry* aims to improve the economics of ethanol production by introducing new feedstocks and processes while maintaining production of value- added byproducts. By introducing new feedstocks, the *Bridge* activity will foster growth within the industry, boosting production to meet forecasted demands. As a cooperative venture, this activity will create win-win situations for participating firms and for the industry as a whole, while expanding the potential of ethanol as a viable alternative transportation fuel.